

| REPORT DOCUMENTATION PAGE   |                             |   |   | Form Approved<br>OMB No. 0704-0188                                 |                           |
|---|-----------------------------|---|---|--|---------------------------|
| The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.<br><b>PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.</b>   |                             |   |   |  |                           |
| 1. REPORT DATE (DD-MM-YYYY)   |                             | 2. REPORT TYPE<br>Conference Proceeding |   | 3. DATES COVERED (From - To)<br>18-22 Nov 2002                     |                           |
| 4. TITLE AND SUBTITLE<br>The Biogeo-Optical Model: The Database & Testing   |                             |   |   | 5a. CONTRACT NUMBER  |                           |
|   |                             |   |   | 5b. GRANT NUMBER   |                           |
|   |                             |   |   | 5c. PROGRAM ELEMENT NUMBER<br>61153N/ 62435N                       |                           |
|   |                             |   |   | 5d. PROJECT NUMBER   |                           |
| 6. AUTHOR(S)<br>Robert H. Stavn, Richard W. Gould, Gia Lamela   |                             |   |   | 5e. TASK NUMBER  |                           |
|   |                             |   |   | 5f. WORK UNIT NUMBER   |                           |
|   |                             |   |   |  |                           |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br>Naval Research Laboratory<br>Oceanography Division<br>Stennis Space Center, MS 39529-5004   |                             |   |   | 8. PERFORMING ORGANIZATION<br>REPORT NUMBER<br>NRL/PP/7330/02/0067 |                           |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)<br>Office of Naval Research<br>800 N. Quincy St.<br>Arlington, VA 22217-5660  |                             |   |   | 10. SPONSOR/MONITOR'S ACRONYM(S)<br>ONR                            |                           |
|   |                             |   |   | 11. SPONSOR/MONITOR'S REPORT<br>NUMBER(S)                          |                           |
|   |                             |   |   |  |                           |
| 12. DISTRIBUTION/AVAILABILITY STATEMENT<br>Approved for public release; distribution is unlimited   |                             |   |   |  |                           |
| <div style="display: flex; justify-content: space-between;"> <div>13. SUPPLEMENTARY NOTES</div> <div style="font-size: 2em; font-weight: bold;">20030523 104</div> </div>   |                             |   |   |  |                           |
| 14. ABSTRACT<br>Parameterization of optical Case 2 waters, especially near-shore waters, continues to challenge our modeling and predictive capabilities because of the significant effect of suspended mineral matter on the optical properties of these waters. It has been pointed out that there is a paucity of optical information for the suspended mineral matter of coastal waters <sup>2,3</sup> . Supplying this gap in our knowledge will create a new field, geo- optics, which is absolutely necessary for construction of adequate coastal optical models and will even be of importance for Case 1 waters when the open ocean receives mineral matter from dust storms and gets a significant admixture of iron for plankton blooms. The majority of activity in the study of ocean optical properties has been the creation of chlorophyll-based models <sup>4</sup> , the quantification of absorption cross sections, and the partitioning of the absorption coefficient into its various organic components <sup>1</sup> . In this report we are making a contribution to the new field of geo-optics by investigating the optical scattering cross section of suspended mineral matter in Mobile Bay, Alabama. Combining these data with bio-optically based optical data on suspended organic matter gives us the biogeo-optical model of coastal ocean optical properties. |                             |   |   |  |                           |
| 15. SUBJECT TERMS<br>parameterization, geo-optics, Mobile Bay   |                             |   |   |  |                           |
| 16. SECURITY CLASSIFICATION OF:   |                             |   | 17. LIMITATION OF<br>ABSTRACT                             |  | 18. NUMBER<br>OF<br>PAGES |
| a. REPORT<br>Unclassified   | b. ABSTRACT<br>Unclassified | c. THIS PAGE<br>Unclassified            | SAR   |  | 6                         |
|   |                             |   | 19a. NAME OF RESPONSIBLE PERSON<br>Rick Gould             |  |                           |
|   |                             |   | 19b. TELEPHONE NUMBER (Include area code)<br>228-688-5587 |  |                           |

# THE BIOGEO-OPTICAL MODEL: THE DATABASE & TESTING

Robert H. Stavn

*Department of Biology, University of North Carolina at Greensboro  
Greensboro, NC 27402*

*Richard W. Gould, Jr.*

*Naval Research Laboratory, Code 7333  
Stennis Space Center, MS 39529*

*Gia M. Lamela,*

*Naval Research Laboratory, Code 7212  
Washington, D.C. 20375*

## INTRODUCTION

Parameterization of optical Case 2 waters, especially near-shore waters, continues to challenge our modeling and predictive capabilities because of the significant effect of suspended mineral matter<sup>1</sup> on the optical properties of these waters. It has been pointed out that there is a paucity of optical information for the suspended mineral matter of coastal waters<sup>2,3</sup>. Supplying this gap in our knowledge will create a new field, geo-optics, which is absolutely necessary for construction of adequate coastal optical models and will even be of importance for Case 1 waters when the open ocean receives mineral matter from dust storms and gets a significant admixture of iron for plankton blooms. The majority of activity in the study of ocean optical properties has been the creation of chlorophyll-based models<sup>4</sup>, the quantification of absorption cross sections, and the partitioning of the absorption coefficient into its various organic components<sup>5,6</sup>. In this report we are making a contribution to the new field of geo-optics by investigating the optical scattering cross section of suspended mineral matter in Mobile Bay, Alabama. Combining these data with bio-optically based optical data on suspended organic matter gives us the biogeo-optical model of coastal ocean optical properties.

The fundamental premise of the biogeo-optical model is that the absorption characteristics of suspended matter can be well described by chlorophyll-based models while the scattering characteristics are largely controlled by suspended mineral concentration. Loisel and Morel<sup>7</sup> have published an array of scattering equations for organic matter in Case 1 waters which cannot be applied alone to Case 2 waters because the suspended organic matter supplies only a fraction of the scattering activity. We will show the importance of inorganic and organic matter for the optical scattering coefficient of Mobile Bay.

## MATERIALS AND METHODS

The research cruise in Mobile Bay took place from 18 - 25 May 2002 and two ships participated, the R/V Ocean Color and the R/V Pelican. The data reported here are those collected from the R/V Ocean Color of Code 7333, Naval Research Laboratory, Stennis Space Center, MS. The sample station pattern was for the Ocean Color to run

transects from deep inside Mobile Bay out past the barrier islands and somewhat into the Northern Gulf of Mexico. Data on optical absorption and scattering were collected from a WET labs AC-9 meter, both from the surface and in depth profile. Surface water samples were also collected at each station and returned to the Dauphin Island Sea Lab for analysis. At the lab water samples were filtered under vacuum through Whatman GF/F, 47 mm diameter, glass fiber filters. The filters had been pre-washed, ashed, and weighed. The volume filtered varied from 200 ml (very turbid sample) to 1.50 l (clear northern Gulf of Mexico sample). The samples were filtered to the clogging of the filter which ensured a relatively consistent amount of suspended material for analysis. After filtration the samples were washed three times in deionized, particle-free water to removed excess salt from the filter residue. The filtered, washed samples were then dried at 103° C for two hours. After two hours the samples were cooled in a dehumidified and weighed. Then the samples were ashed at 550° C for 15 minutes, cooled, and weighed again. The total sample weight is TSS (Total Suspended Solids) while the ashed sample weight is PIM (Particulate Inorganic Matter). The difference between the two above weights is then POM (Particulate Organic Matter). The weights were normalized to the sample volume to obtain a concentration in mg/l, equivalent to g/m<sup>3</sup>. In addition, the surface water samples were analyzed to estimate chlorophyll concentration with an Aquafluor instrument.

The particle scattering coefficients,  $b_p(\lambda)$ , determined from the AC-9 measurements were analyzed with a multiple regression against the concentrations of PIM and POM. From this we were able to assess the relative contributions of suspended mineral and organic matter to the particle scattering coefficient. The regression coefficients from the analysis are then a measure of the spectral optical scattering cross sections of the suspended particulates.

## RESULTS

The concentrations of PIM and POM allowed the prediction of  $b_p(\lambda)$  with an R<sup>2</sup> of better than 0.90. The regression of PIM proved to be linear with a regression coefficient of acceptable accuracy (Table 1.) while the regression of organic matter indicated that it had less direct effect on the  $b_p(\lambda)$  value (Fig. 1).

**Table 1. Spectral Optical Scattering Cross Sections (m<sup>2</sup>/g) for Suspended Mineral Matter. Mobile Bay, May 2002**

|                    |                    |                    |                    |                    |
|--------------------|--------------------|--------------------|--------------------|--------------------|
| $b^*_{pm}(412)$    | $b^*_{pm}(440)$    | $b^*_{pm}(488)$    | $b^*_{pm}(510)$    | $b^*_{pm}(532)$    |
| <b>0.60 ± 0.12</b> | <b>0.59 ± 0.12</b> | <b>0.56 ± 0.11</b> | <b>0.55 ± 0.11</b> | <b>0.53 ± 0.10</b> |
| $b^*_{pm}(555)$    | $b^*_{pm}(650)$    | $b^*_{pm}(676)$    | $b^*_{pm}(715)$    |                    |
| <b>0.52 ± 0.10</b> | <b>0.38 ± 0.12</b> | <b>0.44 ± 0.08</b> | <b>0.42 ± 0.08</b> |                    |

The R<sup>2</sup> values were improved when the concentration of POM in the regression was expressed as,

$$b_{po}(\lambda) = \alpha[\text{POM}]^\beta, \quad (1)$$

were  $b_{po}(\lambda)$  is the scattering coefficient due to suspended organic matter at wavelength  $\lambda$ ,  $\alpha$  is the regression coefficient, and  $\beta$  is a simple power to raise the concentration of POM after the conventions of Loisel and Morel<sup>7</sup>. The power coefficient  $\beta$  tended to hover around the value of 1.5. It was possible to express the mineral scattering relationship as,

$$b_{pm}(\lambda) = a[\text{PIM}], \quad (2)$$

where  $b_{pm}(\lambda)$  is the scattering coefficient at wavelength  $\lambda$  due to suspended mineral matter and  $a$  is the regression coefficient for PIM. The regression coefficient, the slope of the of the scattering coefficient plotted against the concentration of suspended matter, Fig. 1, can be interpreted as the optical scattering cross section of the suspended material relative to its mass concentration. This can be expressed as,

$$a = b^*_{pm}(\lambda), \quad (3)$$

where  $b^*_{pm}(\lambda)$  is expressed in units of  $\text{m}^2/\text{g}$ . The regression with organic matter [POM] was not nearly as robust as the regression with suspended mineral matter [PIM] because the regression coefficient could span zero which never occurred with [PIM]. The weakness of the organic matter regression can be seen in Fig. 1 where there is little apparent relationship with the particle scattering coefficient.

We then compared the organic particle scattering coefficient determined by differencing the mineral particle scattering coefficient and the total particle scattering coefficient with the organic particle scattering coefficient calculated from Loisel and Morel<sup>7</sup>. The wavelength for comparison was 532 nm which was typical of the comparisons at other wavelengths.

**Table 2. Comparison of Organic Particle Scatter Coefficient from Multiple Regression and Organic Particle Scatter Coefficient from Chlorophyll.  
Mobile Bay, May 2002**

|  |   |   |
|--|---|---|
| $b_{po}(532)$<br>Low Suspended<br>Matter Station<br><b>0.34 m<sup>-1</sup></b> | $b_{po}(532)$<br>Medium Suspended<br>Matter Station<br><b>3.02 m<sup>-1</sup></b> | $b_{po}(532)$<br>High Suspended<br>Matter Station<br><b>4.63 m<sup>-1</sup></b> |
| Loisel & Morel<br><b>0.31 m<sup>-1</sup></b>                                   | Loisel & Morel<br><b>1.58 m<sup>-1</sup></b>                                      | Loisel & Morel<br><b>1.89 m<sup>-1</sup></b>                                    |

## DISCUSSION AND CONCLUSIONS

The mineral scattering cross sections determined from the Mobile Bay field exercise (Table 1) are the first ones to be determined directly from mineral mass concentration and the particle scattering coefficient. They agree in magnitude with mineral particulate scattering cross sections determined by Bukata et al<sup>7</sup> from clever

indirect determinations utilizing volume reflectance and a complex multivariate non-linear optimization scheme. The magnitude of the mineral optical scattering cross sections decreases with wavelength, as per Bukata et al's results, but the database used to derive them ( $N = 24$ ) is rather small and the error variation of the cross sections is enough that a spectral dependence cannot be demonstrated statistically. Clearly more data are needed to build up this important geo-optical database.

The principal conclusion drawn from the multiple regression analysis is that the suspended mineral matter is the primary control of the particle scattering coefficient in coastal ocean waters. The clustering of regressions of POM with the particle scattering coefficient illustrated in Fig. 1 clearly indicates that the concentration of organic matter is a poor predictor of the total particle scattering coefficient. When we attempt to predict the organic particle scattering coefficient, just utilizing the chlorophyll concentration<sup>7</sup>, the results in Table 2 indicate that in clearer coastal water, closer to Case 1 water in its optical properties, it is possible to predict the organic particle scattering coefficient from chlorophyll concentration. However, as we encounter sample stations with a greater and greater concentration of suspended particulate matter the organic particle scattering coefficient deviates more and more from the coefficient predicted from chlorophyll concentrations. It is apparent that the appearance of greater amounts of suspended organic matter, much of it likely allochthonous in nature, causes Case 1 based bio-optical algorithms to fail.

Therefore, the key to studying and modeling coastal ocean optics is to characterize the variation of mineral matter and the associated organics, both allochthonous and autochthonous. We have demonstrated that the strongest effect on the particle scattering coefficient is from suspended mineral matter. Thus we need to develop the new field of geo-optics if we are to understand the optics of coastal ocean systems. From this understanding of the source of the remote sensing signal we will be able to develop adequate coastal ocean remote sensing algorithms.

## ACKNOWLEDGMENTS

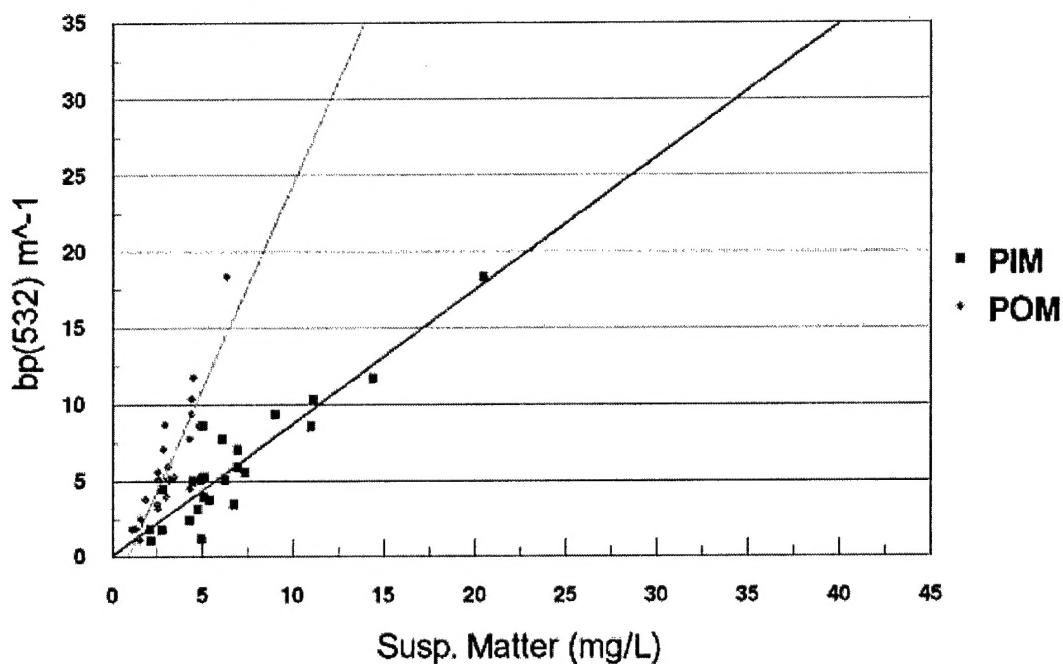
RHS wishes to acknowledge the support of ONR Grant No. N00014-97-1-0812 and several previous ONR grants. RWG, GML, and RHS wish to acknowledge the support of the Naval Research Laboratory, Program Elements 61153N and 62435N.

## REFERENCES

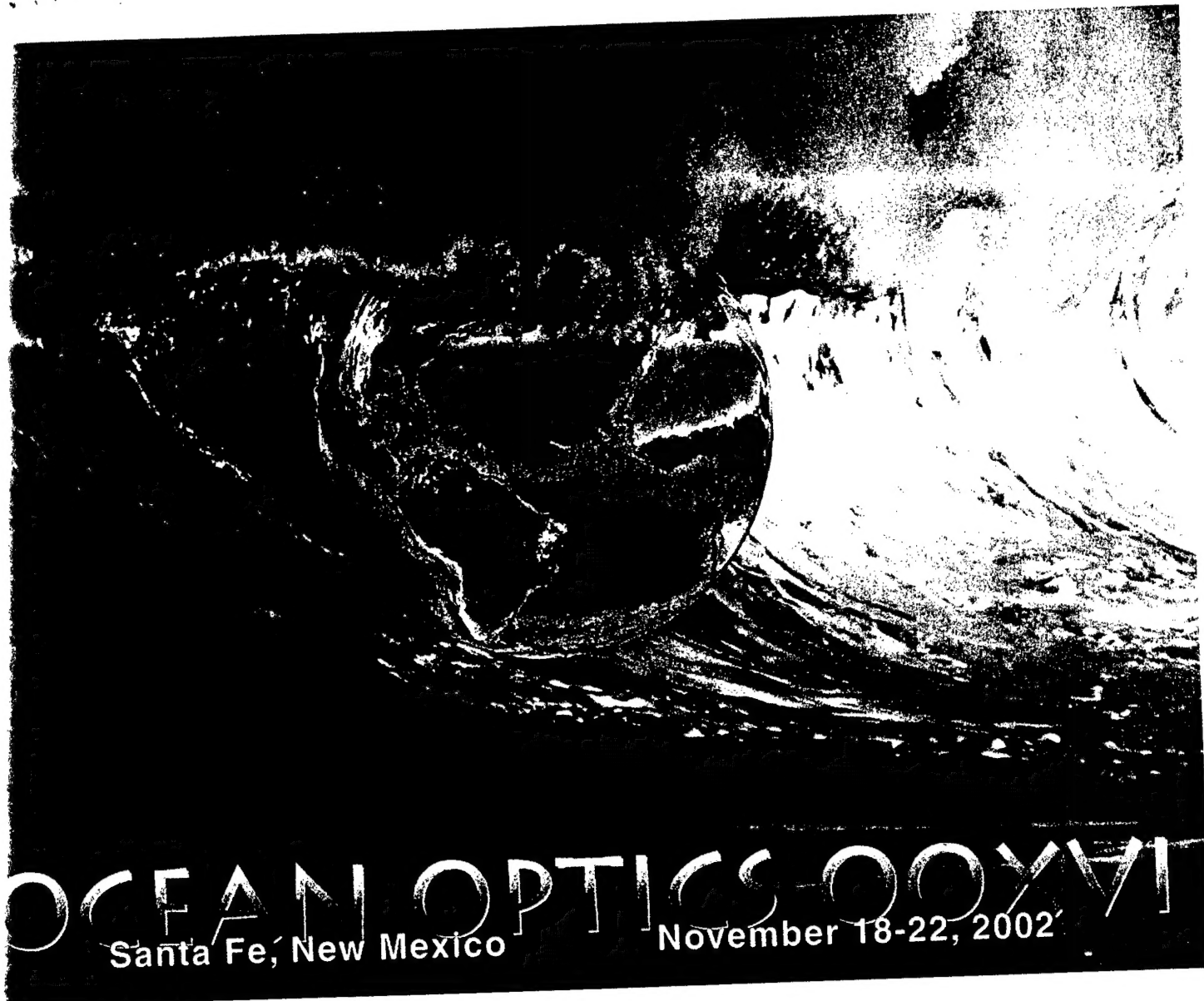
1. . Gordon and A. Morel, "Remote assessment of ocean color for interpretation of satellite visible imagery," in *Lecture Notes on Coastal and Estuarine Studies*, R.T. Barber, C.K. Mooers, M.J. Bowman, and B. Zeitschel, eds., pp. 1-113, Springer Verlag, New York, 1983.
2. . Stavn and A.D. Weidemann, "Coastal optical water type 2: modeling and minerogenic scattering," in *Ocean Optics XIII*, Steven G. Ackleson, Robert Frouin, Editors, Proc. SPIE 2963, 38-48 (1997).

3. .P. Bukata, J.H. Jerome, K.Ya. Kondratyev, and D. V. Pozdnayakov. Optical Properties and Remote Sensing of Inland and Coastal Waters. CRC Press, New York, 362 pp., 1995.
4. V.I. Haltrin, "Chlorophyll-based model of seawater optical properties," *Appl. Opt.*, 38(33), 6826-6832 (1999).
5. J.S. Cleveland, "Regional models for phytoplankton absorption as a function of chlorophyll *a* concentration," *J. Geophys. Res.*, 100(C7), 13,333-13,344 (1995).
6. J.S. Cleveland and M.J. Perry, "A model for partitioning particulate absorption into phytoplanktonic and detrital components," *Deep-Sea Res. I*, 41(1), 197-221 (1994).
7. H. Loisel and A. Morel, "Light scattering and chlorophyll concentration in case 1 waters: A reexamination," *Limnol. Oceanogr.*, 43(5), 847-858 (1998).

## Regressions: Susp. Inorganic & Organic Matter with Particle Scattering



*Figure 1. Individual regressions of Particulate Inorganic Matter (PIM) and Particulate organic matter (POM) from Mobile Bay, Alabama, May 2002.*



OCEAN OPTICS 00YVI  
Santa Fe, New Mexico November 18-22, 2002

## ***Program and Abstracts***

**COVERING A DIVERSITY OF TOPICS PERTAINING TO:**

- Radiative Transfer Theory
- In Situ and Remote Sensor and Measurement System Design
  - Applications of Quantitative Remote Sensing
- Interdisciplinary Processes Pertaining to the Ocean Surface, Volume, and Floor
  - Marine Environment Management Strategies

***Sponsored by:***

*Office of Naval Research  
National Aeronautic and Space Administration*